Tree Root Positioning in Heterogeneous Soil Environment Using GPR

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***Abstract* — The randomness and complexness of the heterogeneous soil make the soil's relative permittivity vary throughout the survey region. The conventional data processing methods, which are based on the assumption that the soil permittivity in the test site is homogenous, yield inaccurate estimation of the roots' positions and thus are not suitable for real GPR surveys. In this paper, we present a new data processing method for accurately positioning tree roots in heterogeneous soil. Numerical experiments are carried out to compare the results of the proposed method and the conventional method. The proposed method outperforms the conventional method in tree root positioning accuracy.**

Keywords— data processing; ground penetrating radar (GPR); heterogeneous soil; numerical experiment.

I. Introduction

Ground-penetrating radar (GPR) has been widely used to investigate tree roots. In the conventional processing frameworks [1], after pre-processing the data, a constant relative permittivity value is estimated for the survey site. This estimated permittivity at a specific location is then used to derive the position of the tree roots across the survey site [2]. However, according to [3], the soil's relative permittivity is very much dependent on its volumetric moisture. Even for different parts of the survey site, the soil's relative permittivity varies significantly due to the difference in water content, sand density, and clay density. Processing GPR data assuming the same relative permittivity leads to inaccurate estimation of the tree roots' positions.

To address this issue, in this paper, we propose a method that estimates the tree roots' position based on analyzing the relative permittivity of the soil surrounding each root. To do so, we first separate the reflection patterns of each tree root. Then, we perform signal processing to estimate the position of the tree root.

In particular, a clustering technique based on the column-connection clustering (C3) method is used to extract each hyperbola (reflection pattern) for individual tree roots [4]. Then, the hyperbola fitting method based on Hough transform (HT) is used to fit each hyperbolic signature. The soil's relative permittivity around each root can then be estimated [5]. After that, the estimated permittivity is used to migrate the hyperbola to a focused point which indicates the position of its corresponding root by using F-K migration [6]. Finally, by combing all the migrated figures, the subsurface roots can be visualized with accurate positions. A numerical experiment is carried out to verify the performance of the proposed method. These results are compared with those of the conventional method. Our proposed method shows an improved positioning accuracy for the tree roots in heterogeneous soil.

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II. Numerical Experiment Setting

The numerical simulation of tree roots in a heterogeneous soil environment is carried out by gprMax software [7]. The simulation scenario is shown in Fig. 1. Three roots r1 – r3 are modeled as three cylinders buried in different areas of the test site. The radii of the roots are 3 cm. The depths of the tree roots are 25 cm and their horizontal positions of r1, r2, and r3 are 50 cm, 100 cm, and 180 cm, respectively. The relative permittivities of the roots are set to 24 and their electrical conductivities are 0.63 mS/m. The magnetic permeabilities and magnetic conductivities are set to 1 and 0, respectively. Parameters of heterogeneous soil are set by using the Peplinski model available in gprMax. In the simulation, the soil has a sand fraction of 0.3, a clay fraction of 0.7, a sand particles density of 2.66 gr/cm^3, a bulk density of 2 gr/cm^3, and a water volumetric fraction varying from 0.01 to 0.15. The number of soil elements and the fractal dimension are set to be 20 and 1.5, respectively. Different colors in Fig. 1 indicate different relative permittivity of the soil.

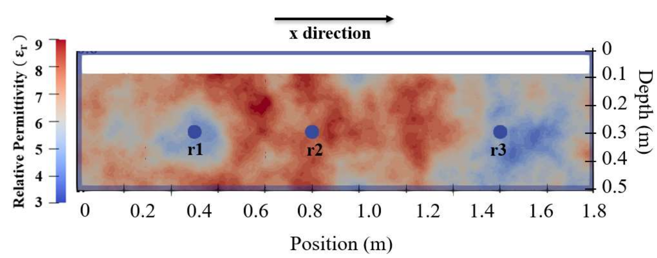

Fig. 1. Side view of the simulation scenario, where r1 to r3 are cylinders representing three roots. The soil's relative permittivity values around r1, r2, r3 are significantly different from each other.

A bi-static model with the polarization of source and probe parallel to the roots' longitudinal dimension is used in the simulation. The source and probe are placed 0.10 m apart from each other and are placed above the soil surface at the height of 0.05 m. The excitation waveform is a Ricker pulse with a central frequency of 1 GHz. The source and probe are moved on a trace along the *x*-direction [Fig. 1] with a step of 0.01 m. 180 A-scan are collected and combined to obtain a B-scan.

III. Result Analysis

Figs. 2(a) and (b) show the time-zero corrected raw B-scan and the pre-processed B-scan, respectively. As shown in Fig. 2(a), root reflections are not distinguishable after the time-zero correction because of the dominating horizontal background clutter. As shown in Fig. 2(b), after background removal, three hyperbolae representing three roots are clearly seen.

In our method, the three hyperbolae are extracted

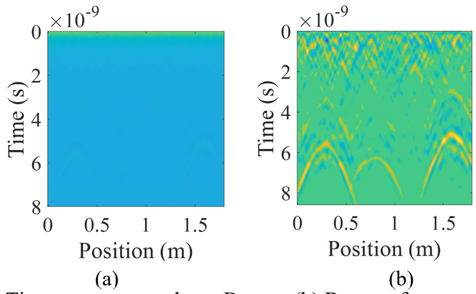

Fig. 2. (a) Time-zero corrected raw B-scan. (b) B-scan after pre-processing techniques.

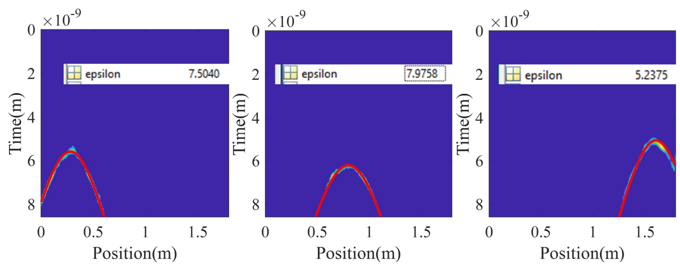

Fig. 3. The extracted hyperbolae corresponding to three roots and the estimated relative permittivity of the surrounding soil of each root.

individually by C3 method and the region around each hyperbola is treated as a region of interest (ROI). The HT method is applied to each ROI to estimate the corresponding relative permittivity of the surrounding soil. The red curves are the fitted hyperbolae corresponding to reflection patterns of the roots [Fig. 3]. We can see in Fig. 3 that the estimated relative permittivity values of the soil (epsilon) surrounding the roots are different, especially the value for r3. The smaller relative permittivity around root r3 can also be seen in Fig. 1.

The F-K migration technique is used to focus each hyperbola using their corresponding soil relative permittivity. In this step, the ordinate is transformed from time to depth. Three focused points are generated. In the final stage, three focused points are combined in one image. As shown in Fig. 4(a), the proposed framework well restores the simulated scenario of Fig. 1. Both the depths and the horizontal positions of the roots are accurately estimated. Fig. 4(b) shows the result for the same scenario processed using the conventional framework for comparison purposes. The relative permittivity of the soil surrounding root r1 is used to estimate all roots' positions. We can see that three roots appear at different depths, which does

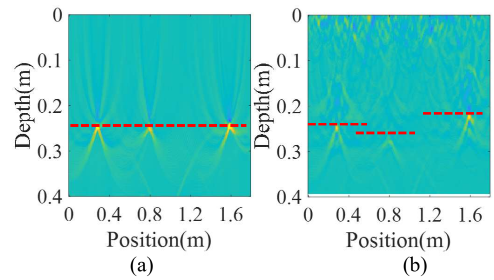

Fig. 4. The output images of (a) the proposed framework and (b) the conventional framework.

not agree with the real scenario. We also perform several experiments with different scenarios and different soil contents. The root mean squared relative error (RMSRE) is used to evaluate the performance. The average RMSREs for depths and horizontal positions obtained by our proposed method are 7.2% and 1.3%, respectively, while those obtained by the conventional method are 11.5% and 1.5%, respectively. The proposed method performs better than the conventional method in estimating the roots' positions.

IV. Conclusion and Perspectives

This paper presents a method to estimate the roots' positions in heterogeneous soil. Numerical experiments have been carried out to verify the performance of the proposed method. Compared with the conventional methods, the proposed method achieves higher accuracy in recovering the roots' positions. The proposed scheme is promising to map the root systems in the areas where heavy rainfall frequently occurs, like tropical regions, where soil permittivity changes drastically due to different moisture content of the field.

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